

# Standard Model Signals and New Physics Constraints

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for the CDF and D0 Collaborations

APS April Meeting

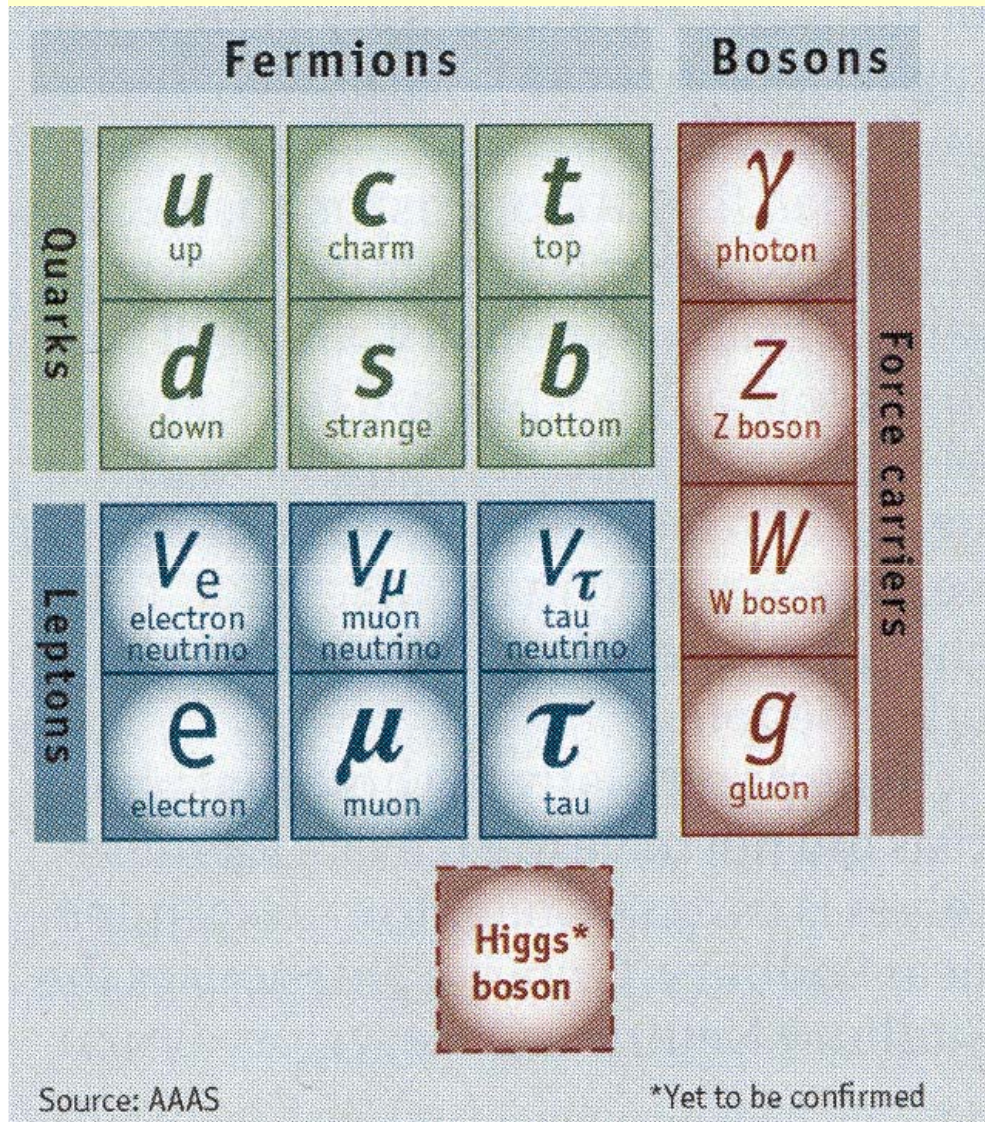
Apr 12, 2008

# Searches at Hadron Colliders

- The Tevatron is a discovery machine
  - Hadron collider:
    - Quark constituents of  $p$ ,  $pbar$  experience all known forces.
    - Interactions at a range of center-of-mass energies.
  - Highest energy fundamental collisions ever artificially produced
  - Two well established detectors.



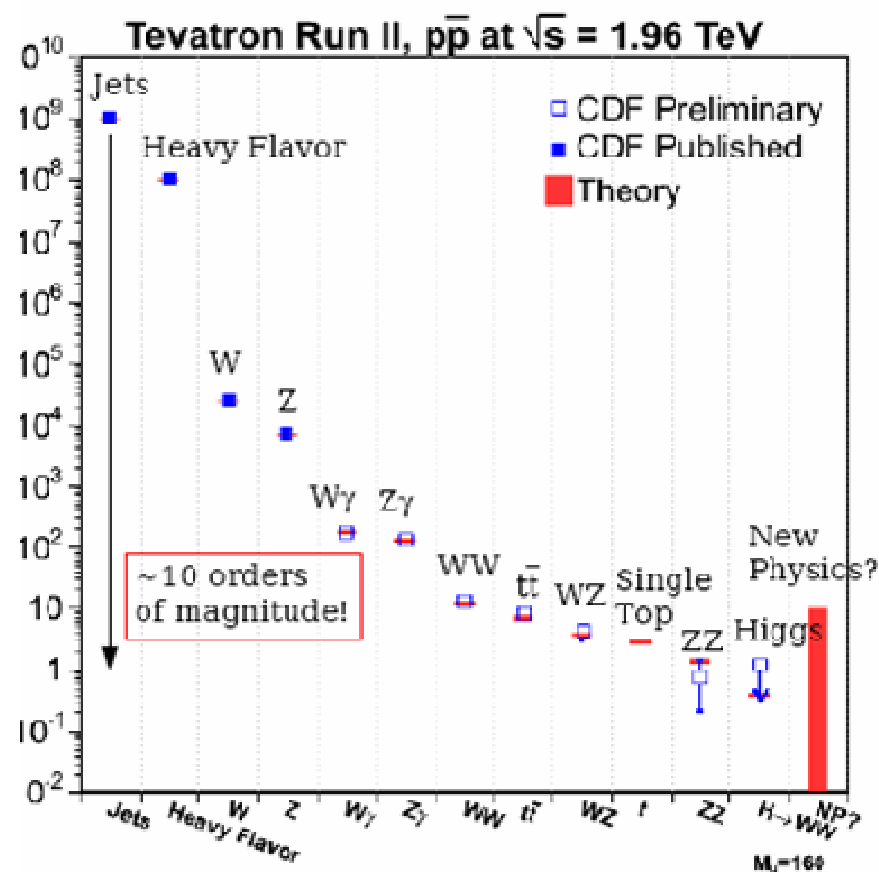
# The Standard Model



- Particle physicists:  
Bearers of the faltering  
standard of reductionism
- The Standard Model (SM)  
is the framework for all  
analysis.
- Incomplete!
  - Higgs (Winer, next  
talk)
  - Unanswered questions

# Searches and Discoveries

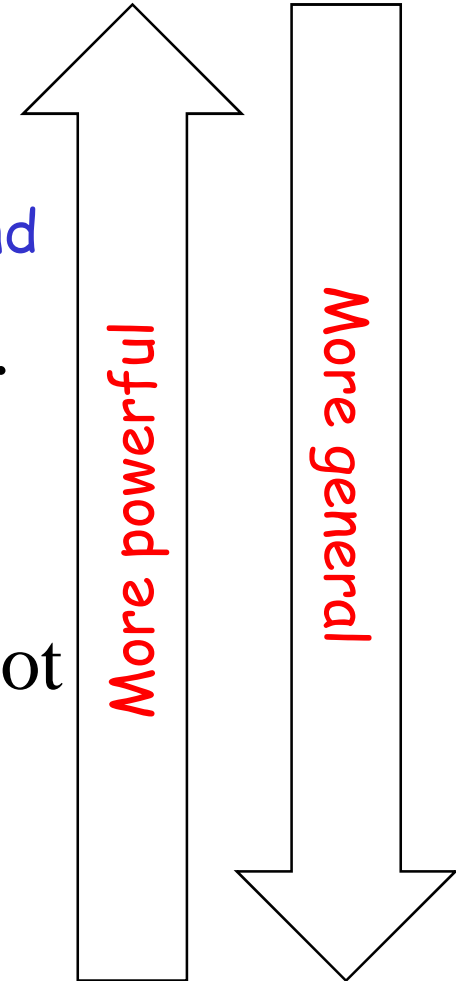
- What constitutes a discovery?
  - That which is experimentally observed or verified for the first time.
- No new physics in early Tevatron running.
  - Mine the data for interesting signals with ever more precision.
- Low-rate SM processes
  - Interesting in their own right.
  - Invaluable laboratory for validating tools and techniques.





# Search strategies

- If you know what you're looking for.  
Tune cuts, develop powerful discriminants  
to separate known signal, known background
- If you're interested in a class of models.  
Define classes of interesting events. Set  
limits in model parameter space.
- If you want to produce generic results not  
tied to a specific model.  
Signature-based searches.  
Consistency with null hypothesis (SM).  
Generic limits on NP cross-sections.



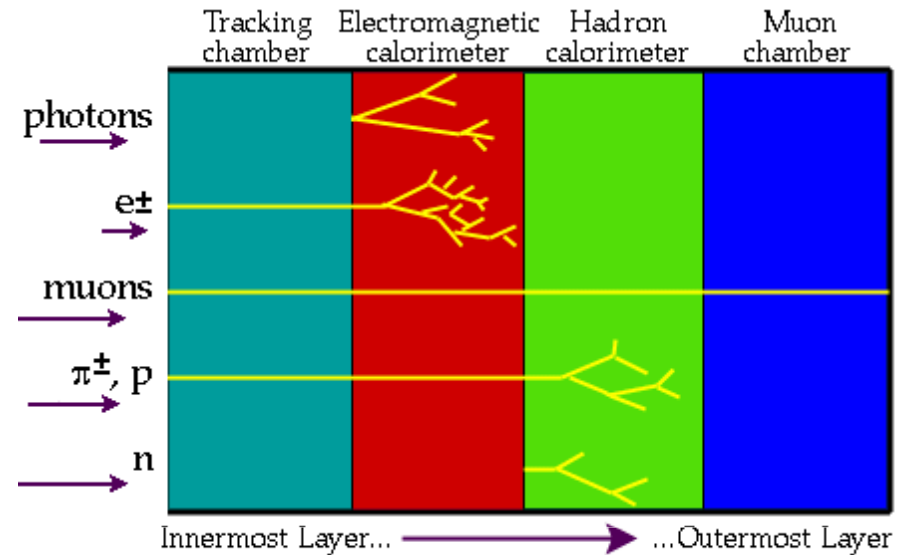
# Experimental signatures

- Search final states with:

- Photons
- Electrons
- Muons
- Taus
- Missing Energy
  - Neutrinos
  - New non-interacting particles
- Hadronic jets (quarks, gluons)
- Heavy flavor jets (bottom, charm)

- Experimental challenges:

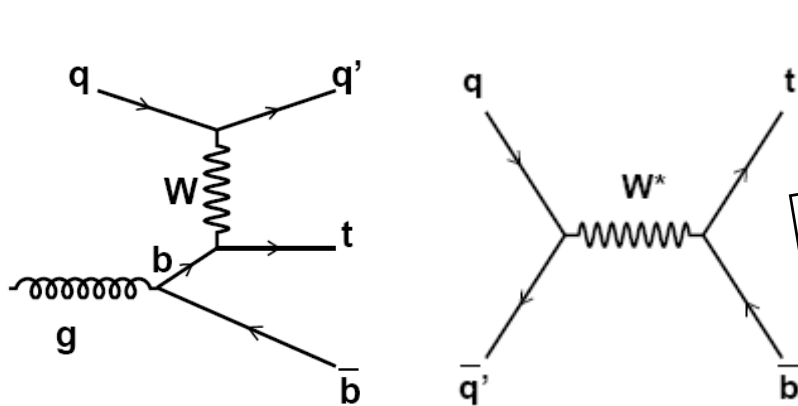
- Particle identification (efficiency?)
- Energy / momentum measurement (calibration?)
- Triggering (rejection factor  $10^4$ )



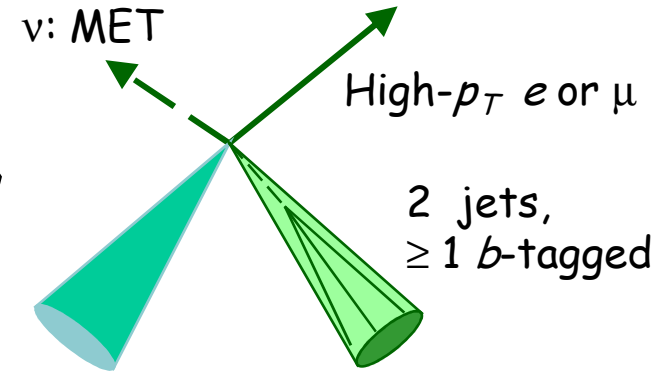
# Results outline

1. A successful search for a small signal at the Tevatron: single top quark production.
2. Global search for new physics.
3. Specific models and final states.
  - Resonances ( $t\bar{t}$ , dielectron)
  - SUSY (Chargino/neutralino, squark/gluino, stop/sbottom)
  - Non-SM Higgs

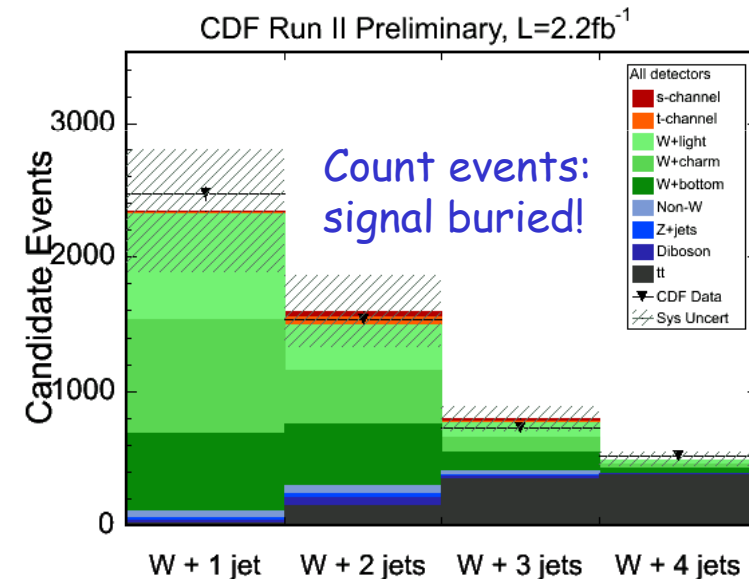
# Single top search intro



What we see



- Electroweak production of top quarks.
  - $\sim 3$  pb predicted in SM
- Rate  $\propto |V_{tb}|^2$
- Sensitive to new physics
- Same final state as WH

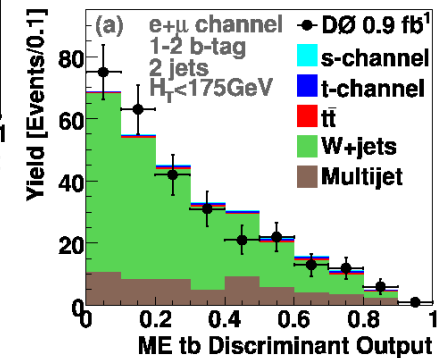
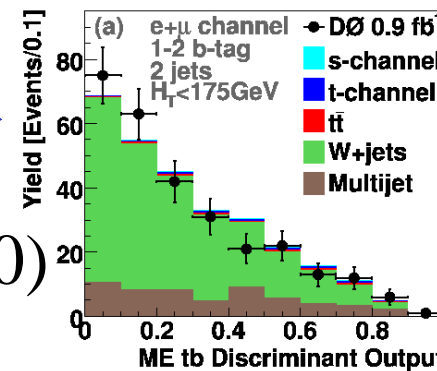
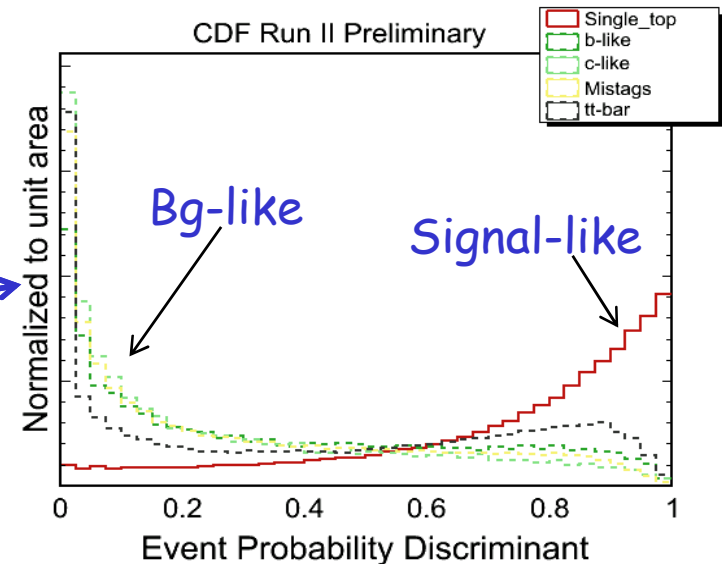


- Need advanced techniques...

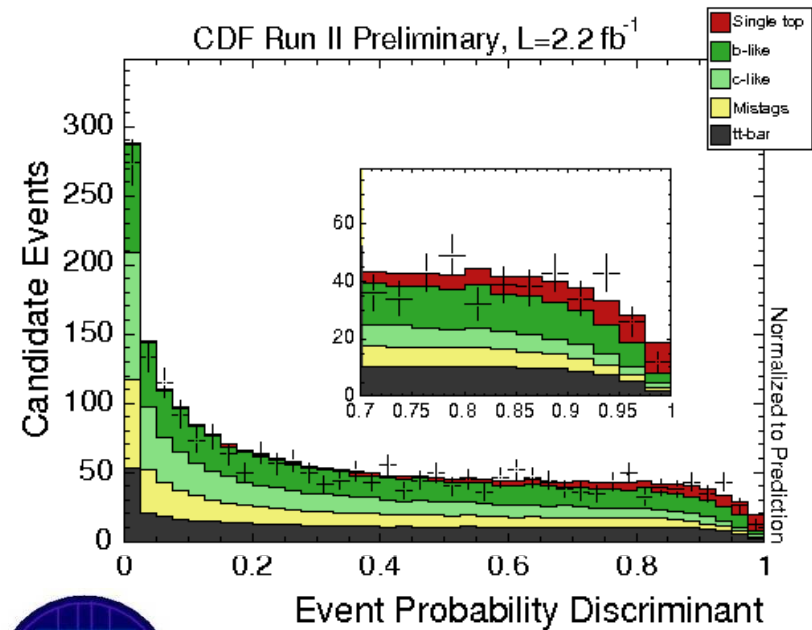
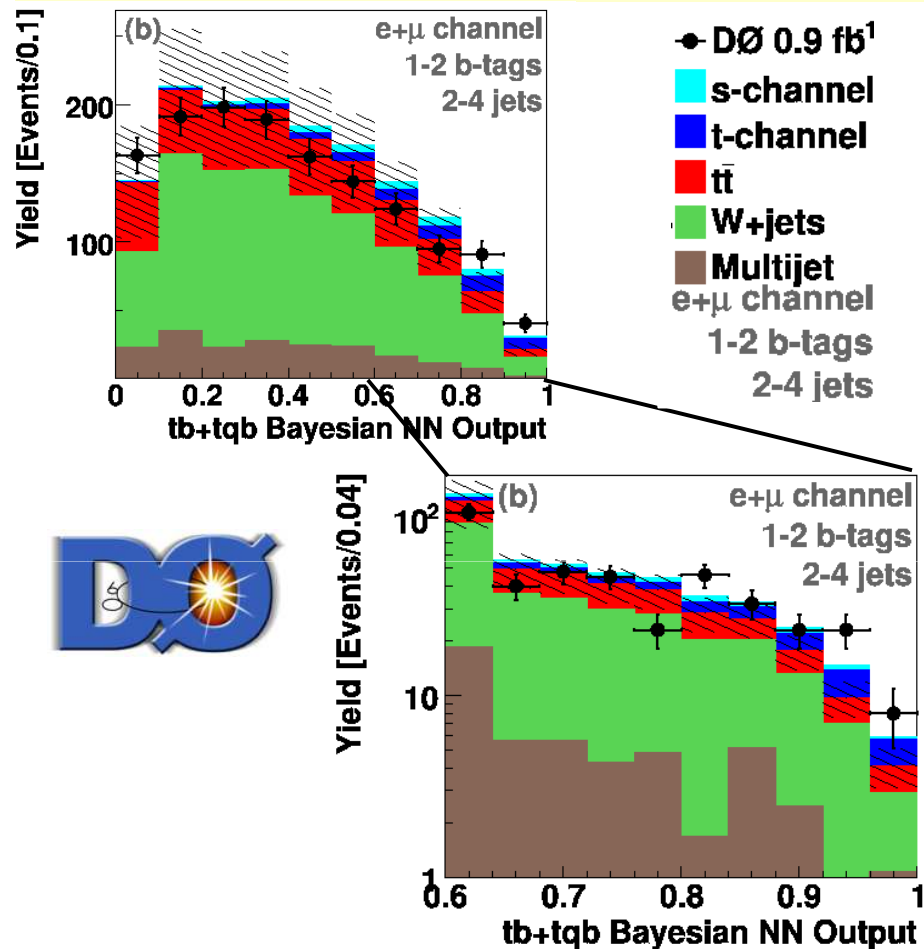


# Single top search techniques

- Signal characteristics known
  - Use the information to maximize signal/background discrimination.
- Multivariate techniques
  - Classify events according to signal-like-ness.
- Must validate background shapes in signal region
  - Data control samples
  - Systematics
- Multiple analyses (5 CDF, 3 D0)
  - Robust results, cross-checks, collaboration.



# Single top results (1)



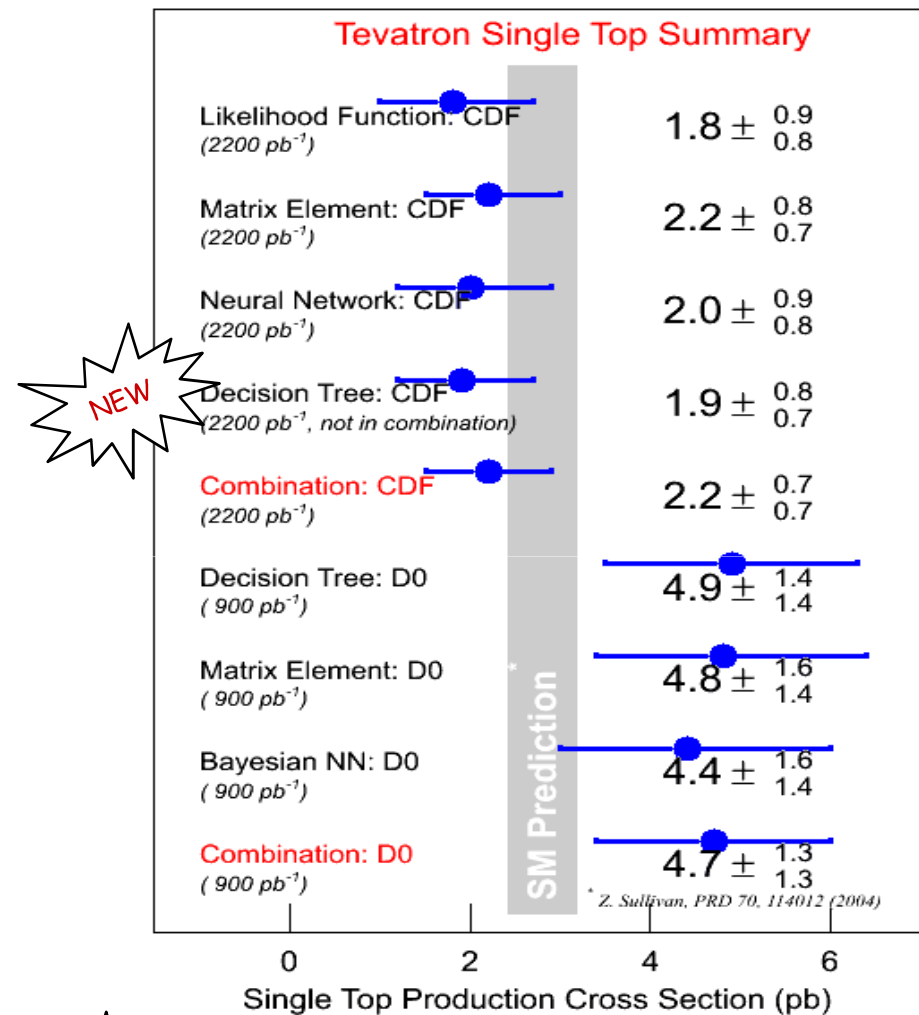
Example analysis and channel from each experiment.

Next combine results for added power...

# Single top results (2)

- Combine results within experiment
  - D0: Best Linear Unbiased Estimator (BLUE)
  - CDF: Asymmetric Iterative BLUE; Evolved Neural Networks

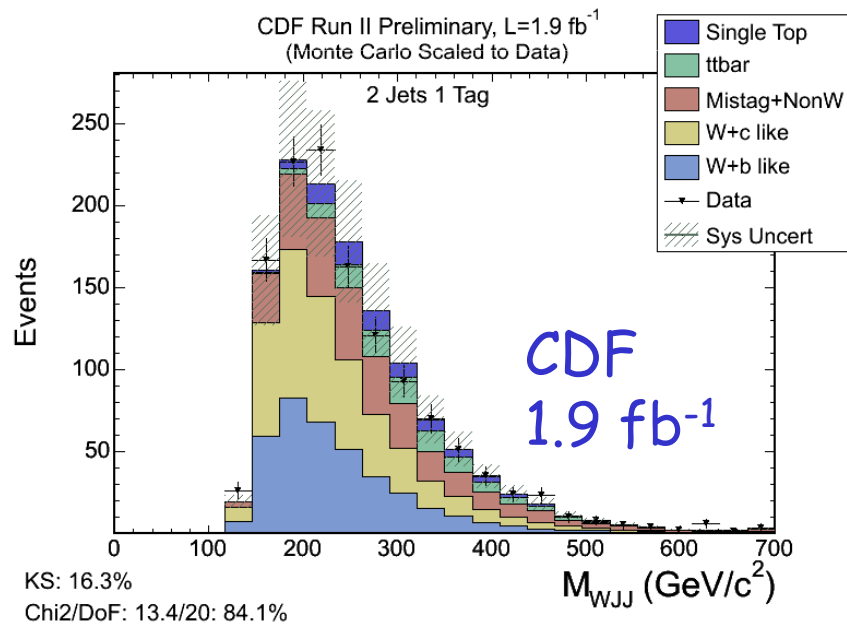
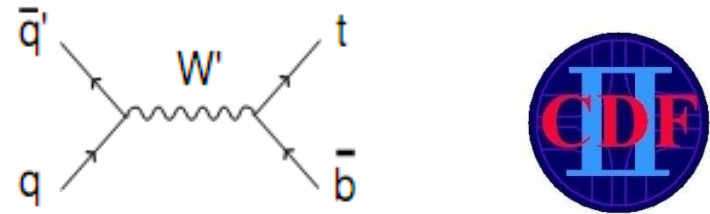
Signal Significance		Cross-Section
Expected	Observed	Measured
D0 (900 pb <sup>-1</sup> )		
2.3σ	3.6σ	4.7 ± 1.3 pb
CDF (2200 pb <sup>-1</sup> )		
5.1σ	3.7σ	2.2 ± 0.7 pb



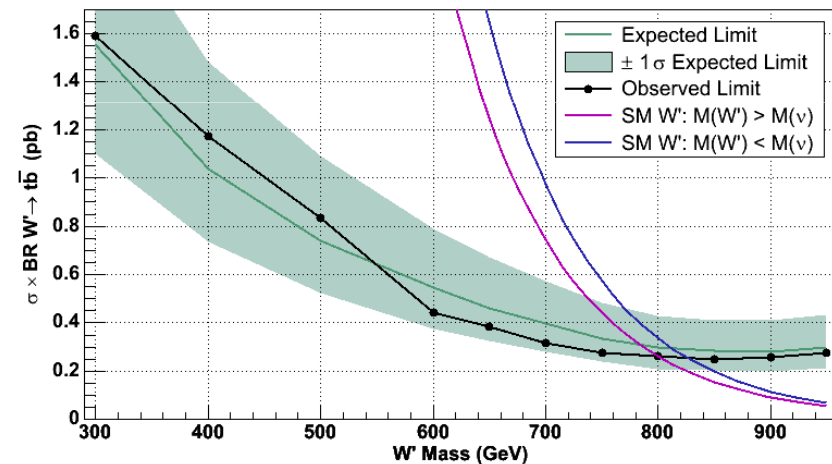
NEW + S-channel optimized (CDF):  
 $\sigma_s = 0.58 + 0.86/-0.58 \text{ pb}$

# Search for $W'$ in single top sample (1)

- Use same tools to search for structure in  $M_{Wjj}$ .
  - Massive W-like boson ( $W'$ ) predicted in various models.
  - No deviation from SM observed; set limits assuming SM-like fermion couplings.



95% C.L. Observed Limit - CDF Run II Preliminary:  $1.9 \text{ fb}^{-1}$

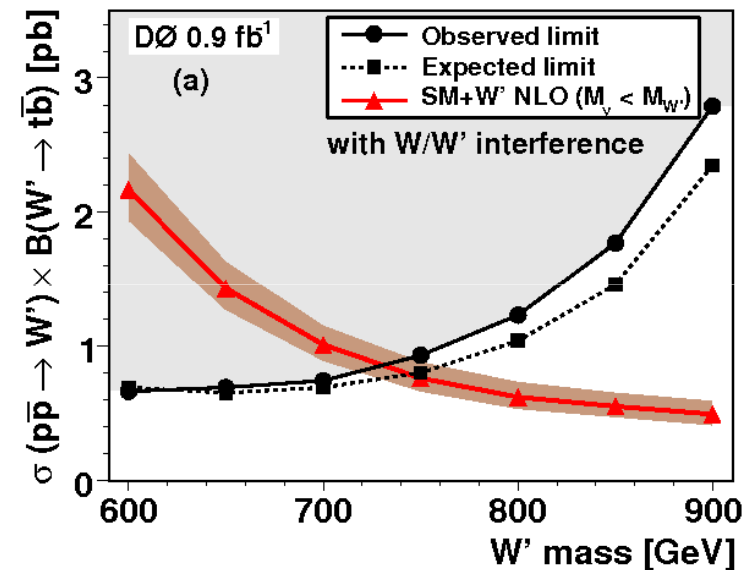
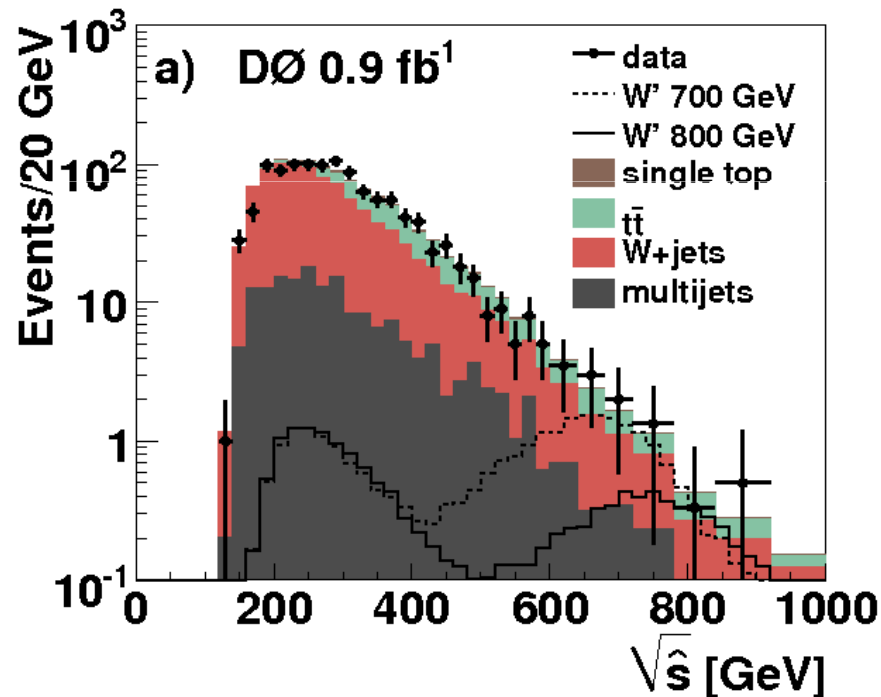


$$M_{W'} > 800 \text{ GeV/c}^2 \quad (M_{W'} > M_{vR})$$

$$M_{W'} > 825 \text{ GeV/c}^2 \quad (M_{W'} < M_{vR})$$

# Search for $W'$ in single top sample (2)

- D0 performs a similar search.
- For  $W'_L$ , interference with SM  $W$  boson is taken into account.



$$M_{W'_L} > 731 \text{ GeV}/c^2$$

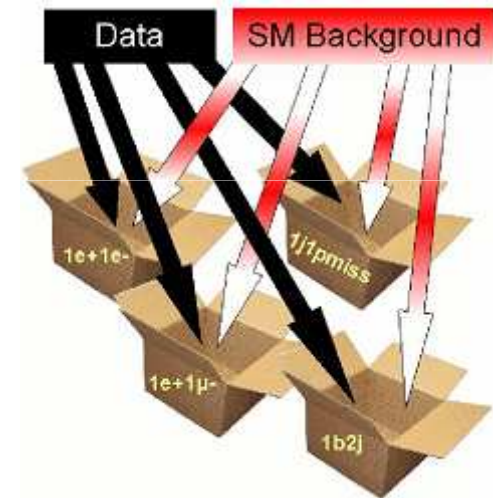
$$M_{W'_R} > 739 \text{ GeV}/c^2 \quad (M_{W'_R} > M_{\nu_R})$$

$$M_{W'_R} > 768 \text{ GeV}/c^2 \quad (M_{W'_R} < M_{\nu_R})$$

# CDF global search for new physics



- Analyze all high- $p_T$  data simultaneously for evidence of new physics.
  - Less sensitive than dedicated analyses.
  - Motivation: don't miss something obvious for failure to look!
- Every event categorized by identified physics objects ( $p_T > 17$  GeV).
  - ~400 exclusive final states
- SM expectation modeled by
  - Pythia & Madgraph generators
  - Full detector simulation
  - Fitted global corrections (43) to theoretical & experimental models





# CDF global search results (1)

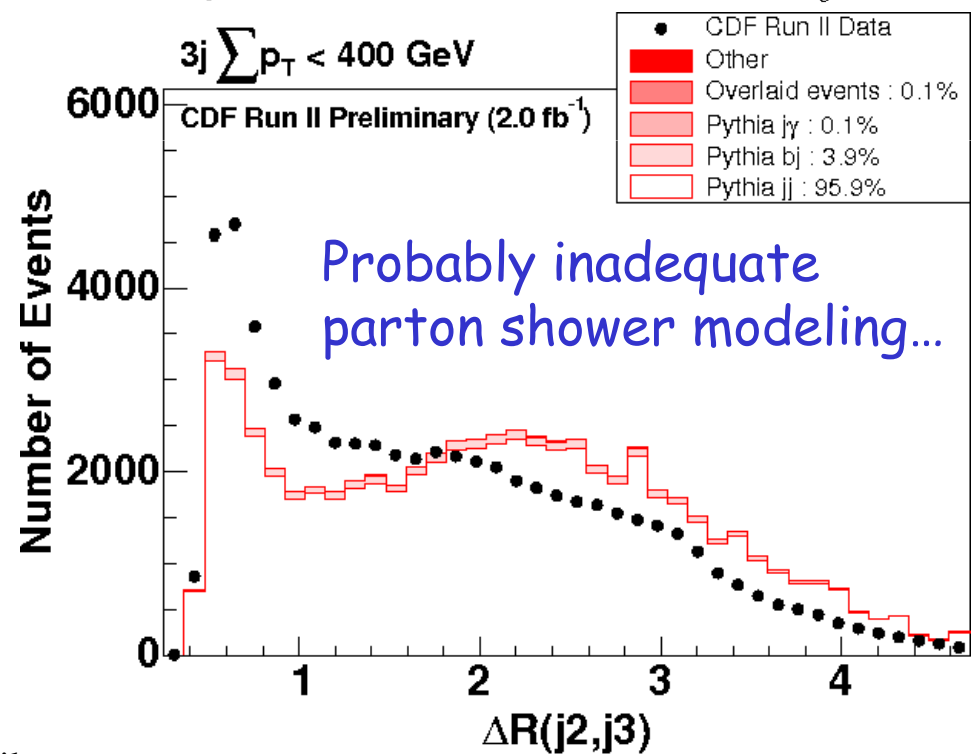
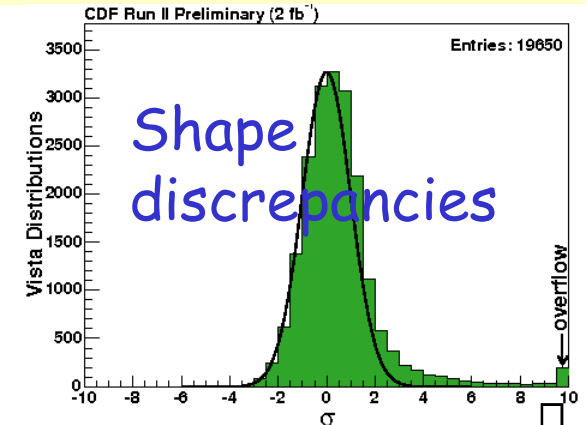
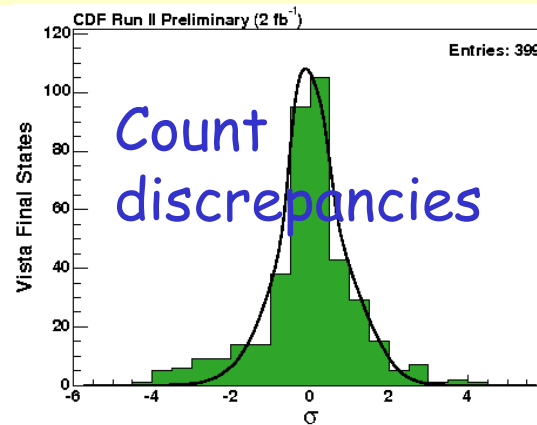
- Look for
  - Deviations in event counts & ~20,000 kinematic distributions.



2 fb<sup>-1</sup>

- Localized excesses (bumps) in ~5000 mass distributions.

No sign of new physics

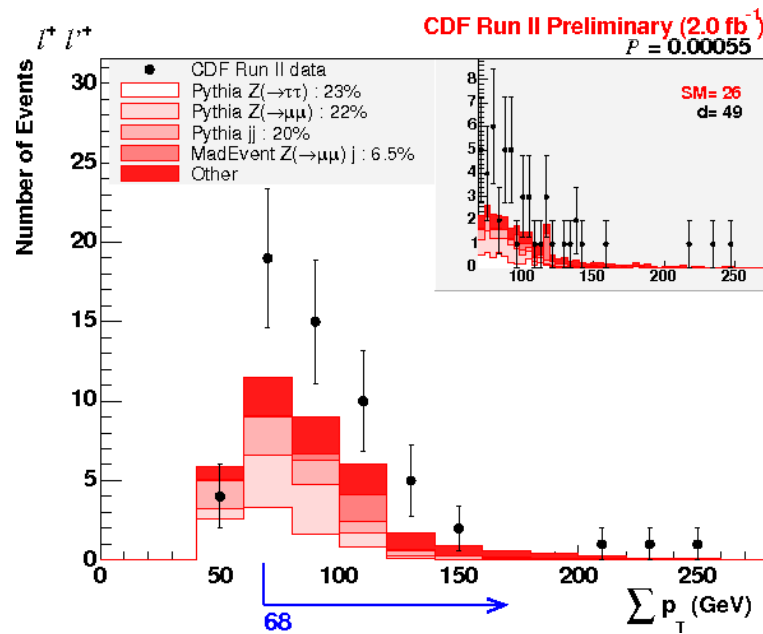


# CDF global search results (2)

- Look for
  - Excesses in high- $p_T$  tails.
    - Algorithm determines most discrepant region
    - Correct probability for trials factor

Global p-value = 0.08.

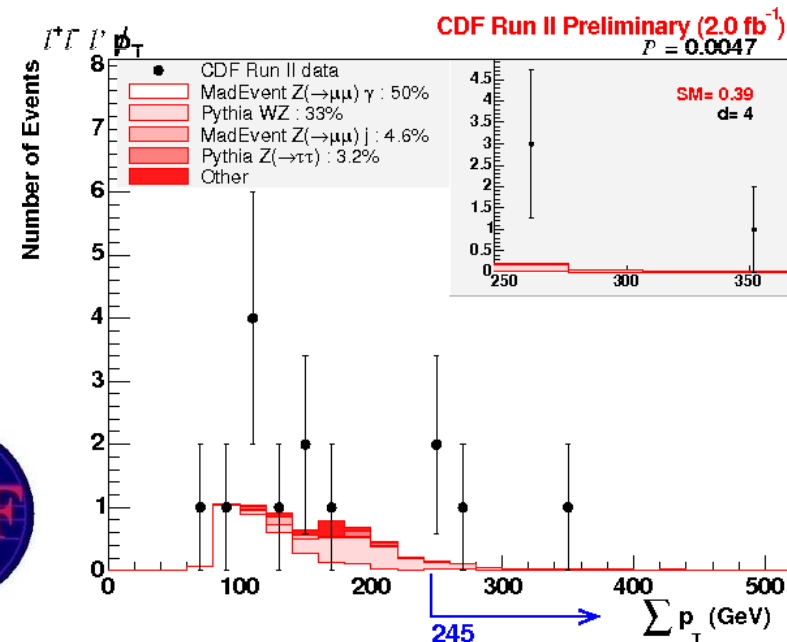
No evidence of new physics in  $2.0 \text{ fb}^{-1}$  of CDF data from the global search.



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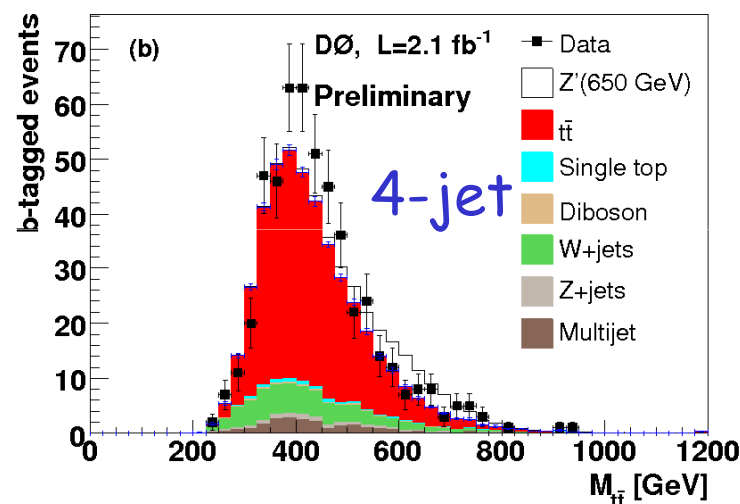
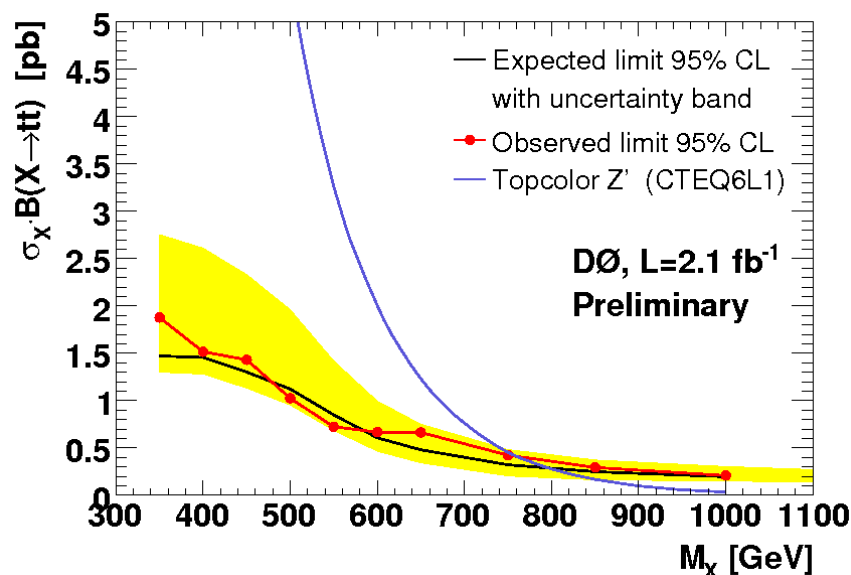


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**Session X12**

# Resonance searches: $t\bar{t}$

- Many models predict new resonances decaying to pairs of SM particles.
  - KK states,  $Z'$ , etc.
- Top quark could have large coupling to new physics...
- Select  $t\bar{t}$  events with  $\geq 1$  NN btag; allow 3-jet events for increased statistics.



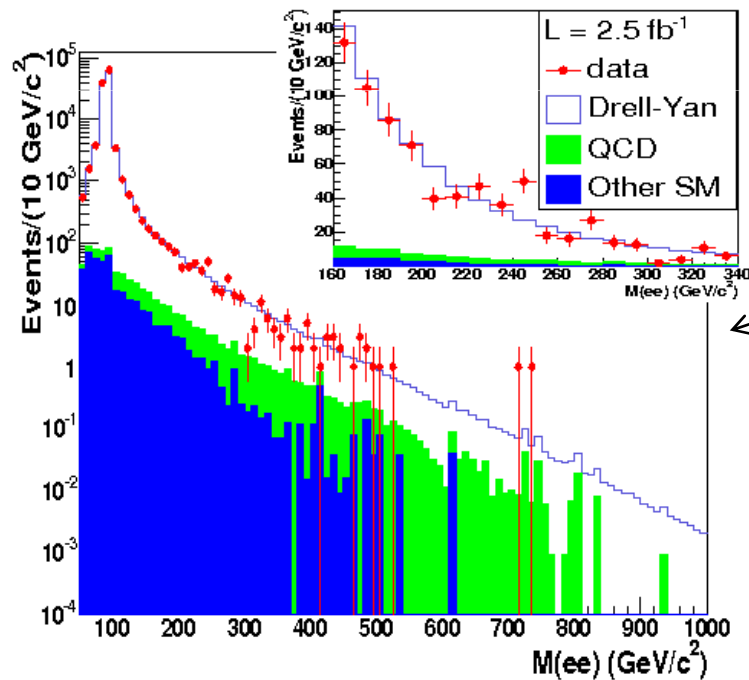
Narrow leptophobic  $Z'$ :  
 $M_{Z'} > 760 \text{ GeV}/c^2$   
 (expected:  $795 \text{ GeV}/c^2$ )

# Resonance searches: ee

- Dielectron events:
  - Very clean signal
  - Excellent calibration using Z peak.



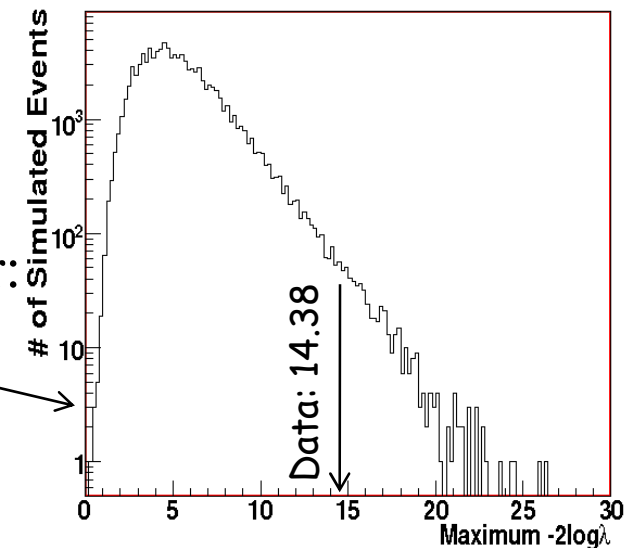
CDF Run II Preliminary



Excess near  
240 GeV/c<sup>2</sup>:  
 $\sim 3.8 \sigma$

After trials factor:  
 $\sim 2.5 \sigma$

CDF Run II Preliminary



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# Supersymmetry

Extension of space-time symmetry.

$$Q |\text{Boson}\rangle = |\text{Fermion}\rangle$$

$$Q |\text{Fermion}\rangle = |\text{Boson}\rangle$$

Every particle has a superpartner.

Addresses problems.

- Dark matter
- Hierarchy
- Unification
- Strings

R-parity:

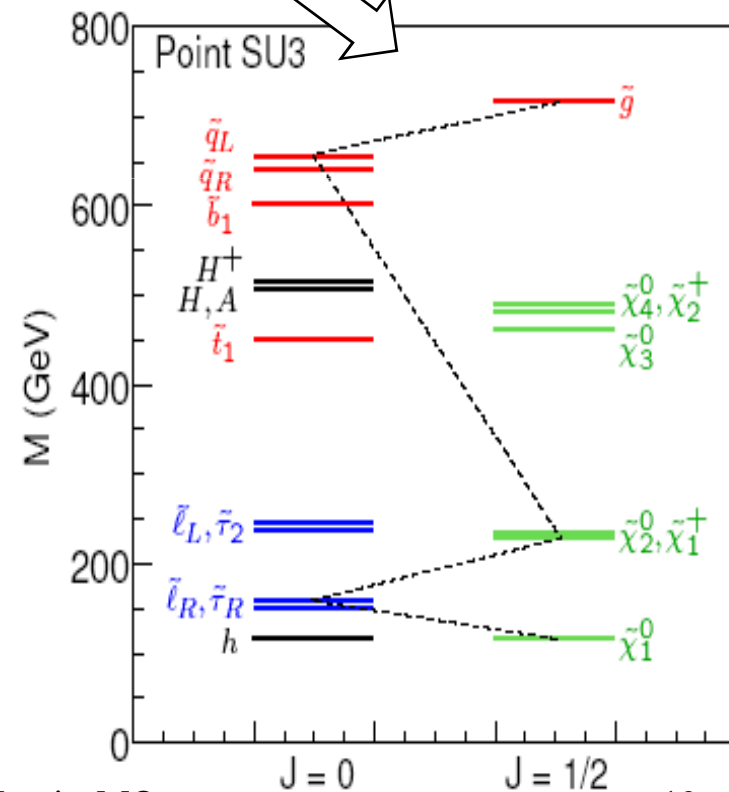
→ Lightest supersymmetric particle (LSP) is stable.

→ SUSY particles pair-produced.

Must be broken.

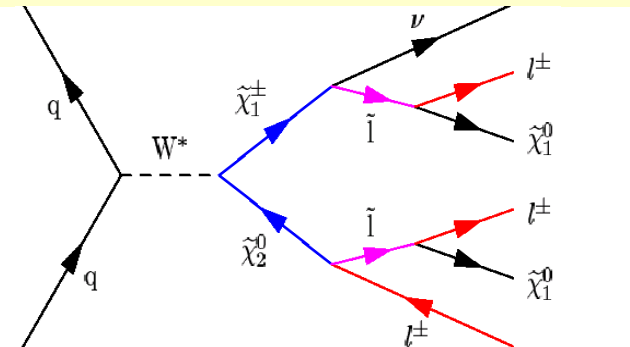
Many new parameters.

MSSM/mSUGRA most common framework.

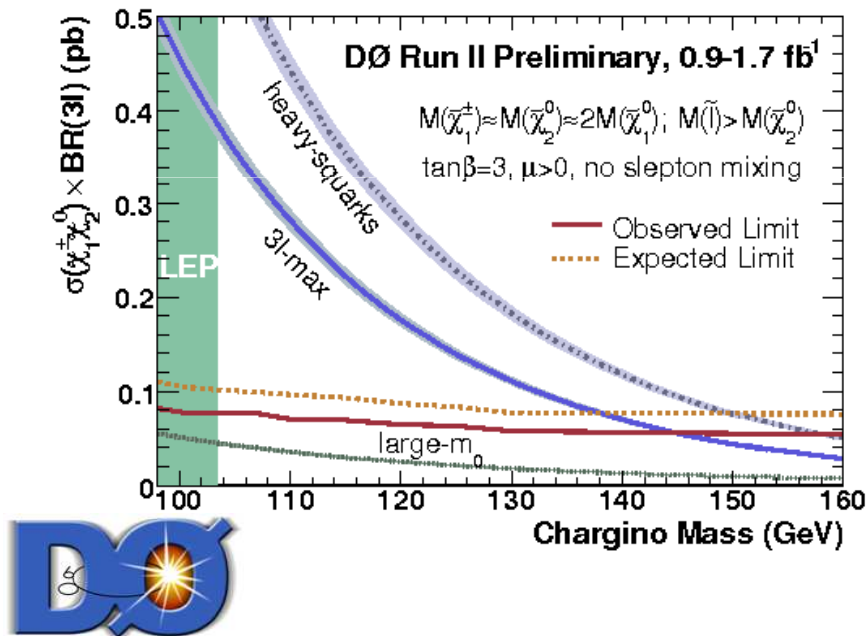


# Chargino/Neutralino results

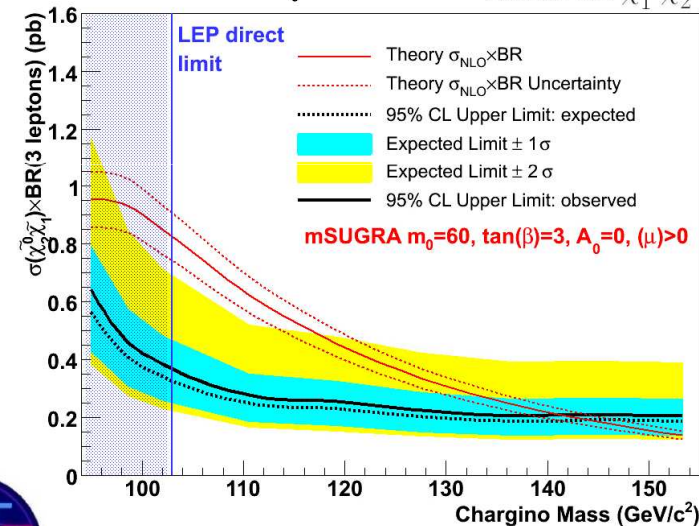
- Low mass scales, but clean signal with multiple leptons, MET
- Optimize channels independently
- Expect O(10) SM events.
- Data consistent with SM prediction.



CDF Run II Preliminary  $\int \text{Ldt} = 2.0 \text{ fb}^{-1}$  Search for  $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$



No slepton mixing:  $M(\tilde{\chi}_1^\pm) > 145 \text{ GeV}/c^2$

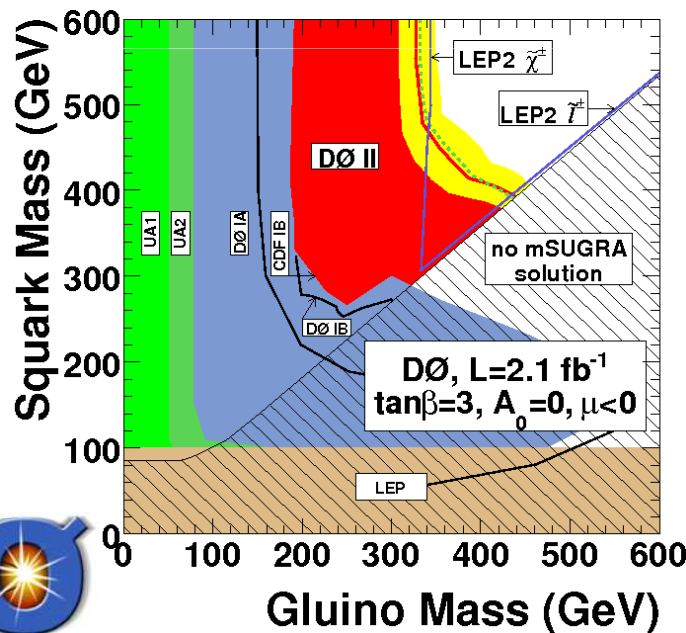
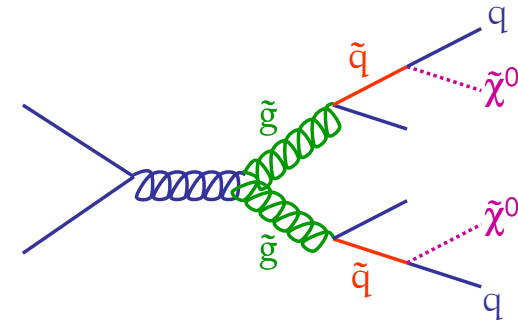


mSUGRA:  $M(\tilde{\chi}_1^\pm) > 140 \text{ GeV}/c^2$

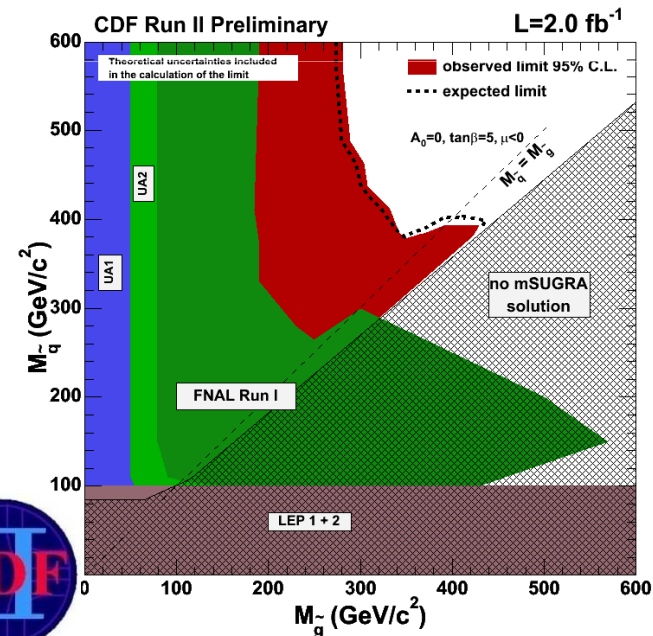


# Squark/gluino results

- Higher mass scales, but strong production  $\rightarrow$  high rates.
- Hadronic jets and missing energy
  - Large SM backgrounds from generic QCD,  $W$ +jets,  $t\bar{t}$
- After cuts, expect  $O(100)$  SM events.
- Data consistent with SM prediction



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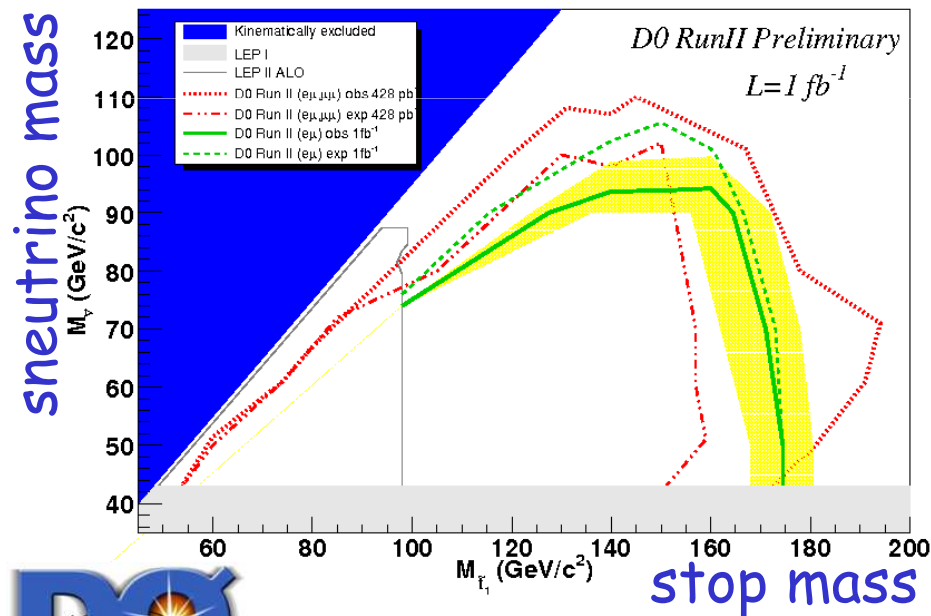


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# Light stop/sbottom results

- $\tilde{t}_1 \rightarrow b l \tilde{\nu}$      $\tilde{\nu} = \text{LSP}$
- Final state:  $e + \mu + \text{MET} (+bb)$
- Data consistent with SM prediction

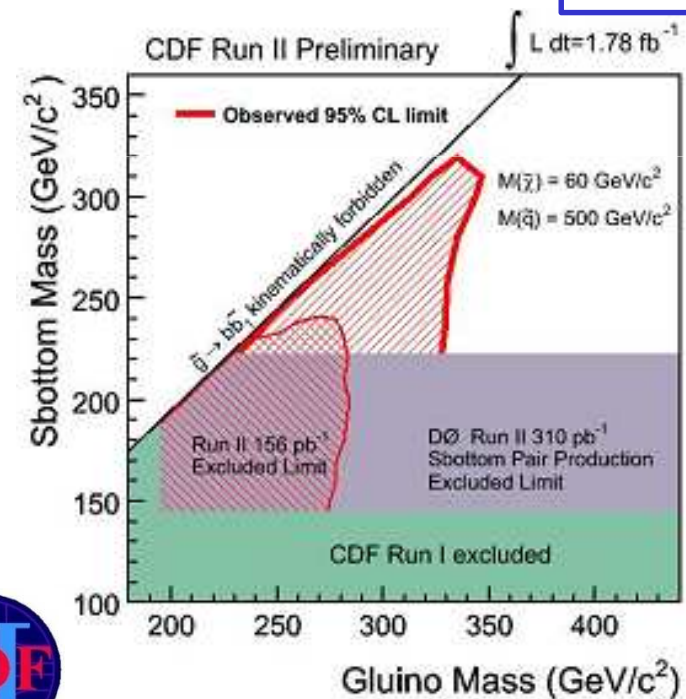
1 fb<sup>-1</sup>



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- $m_{\tilde{g}} > m_{\tilde{b}} : \tilde{g} \rightarrow b\tilde{b}, \tilde{b} \rightarrow b\tilde{\chi}^0$
- Final state: 4b + MET
- Data consistent with SM prediction

1.8 fb<sup>-1</sup>

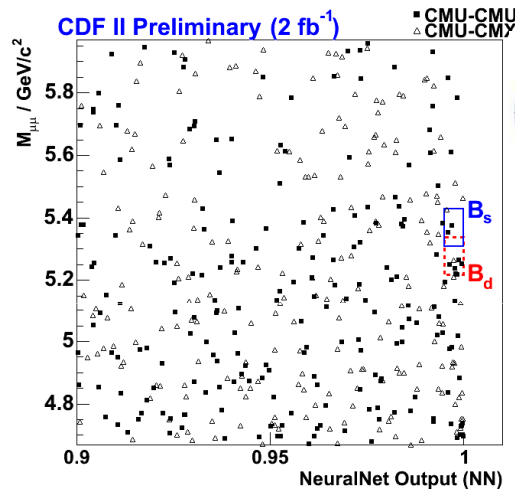


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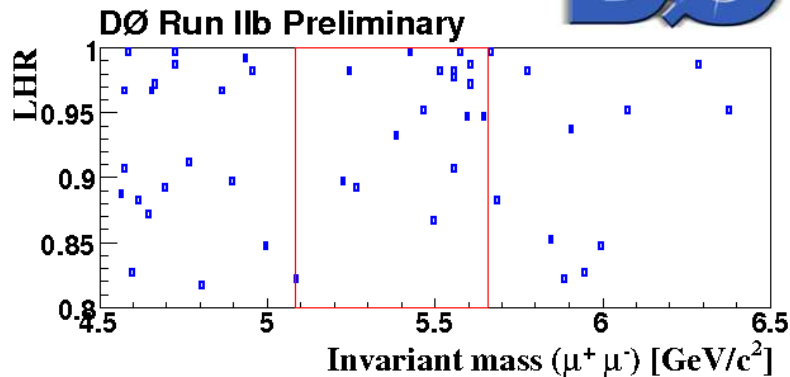
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# $B_s \rightarrow \mu\mu$

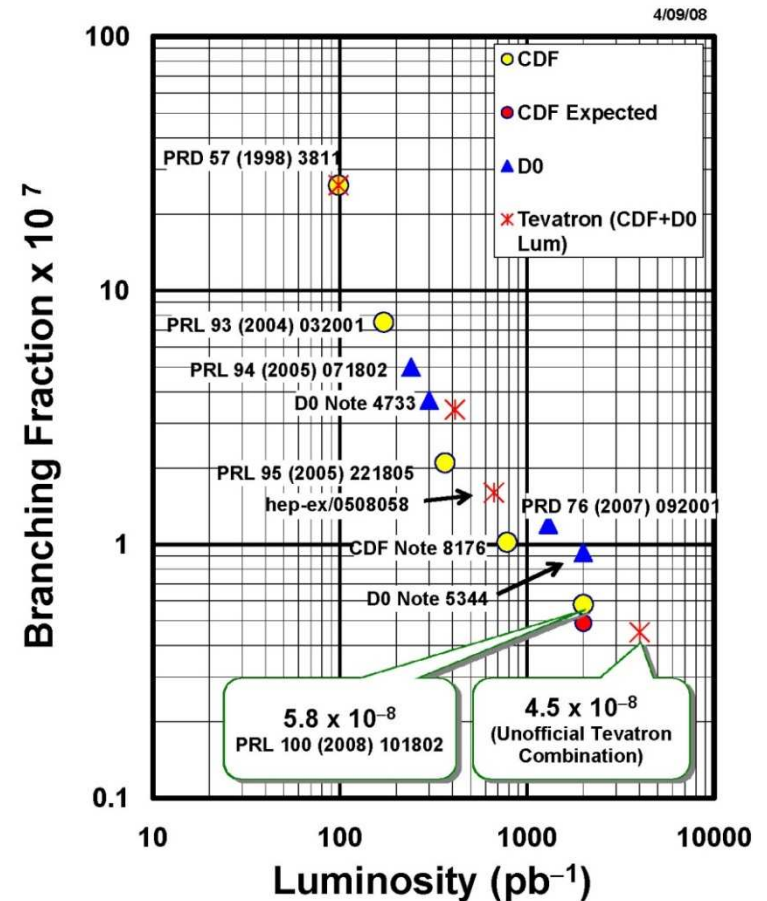
- $\text{BR}_{\text{SM}}(B_s \rightarrow \mu\mu) \approx 3.8 \times 10^{-9}$
- SUSY:  $\propto (\tan \beta)^6$



- Sensitive discriminant
- Determine background from sidebands



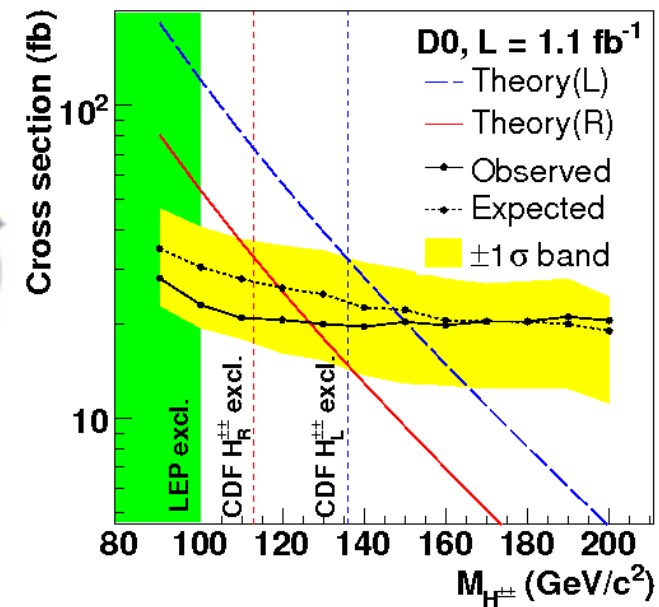
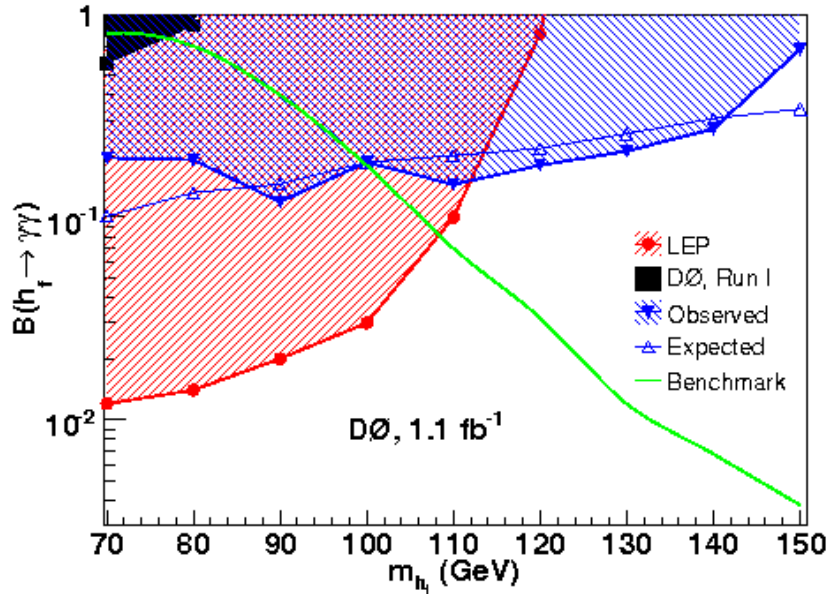
## 95% CL Limits on $\mathcal{B}(B_s \rightarrow \mu\mu)$



CDF:  $\text{BR}(B_s \rightarrow \mu\mu) < 5.8 \times 10^{-8}$  @95% CL  
 D0:  $\text{BR}(B_s \rightarrow \mu\mu) < 9.3 \times 10^{-8}$  @95% CL

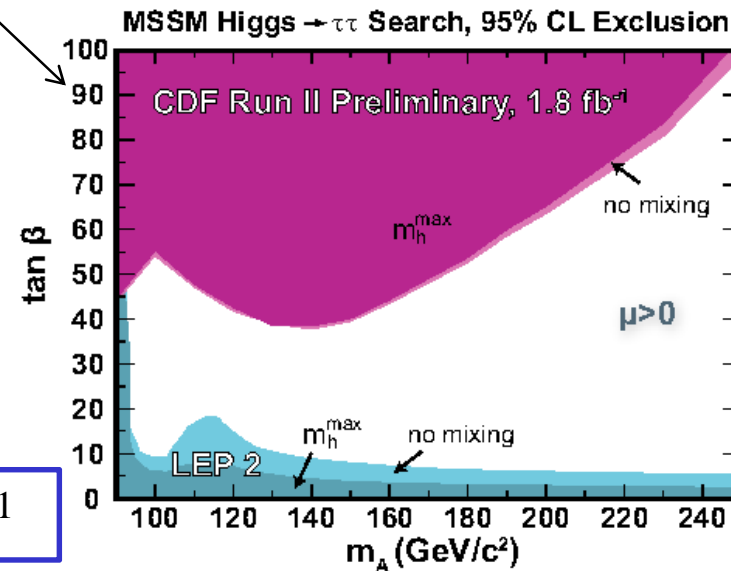
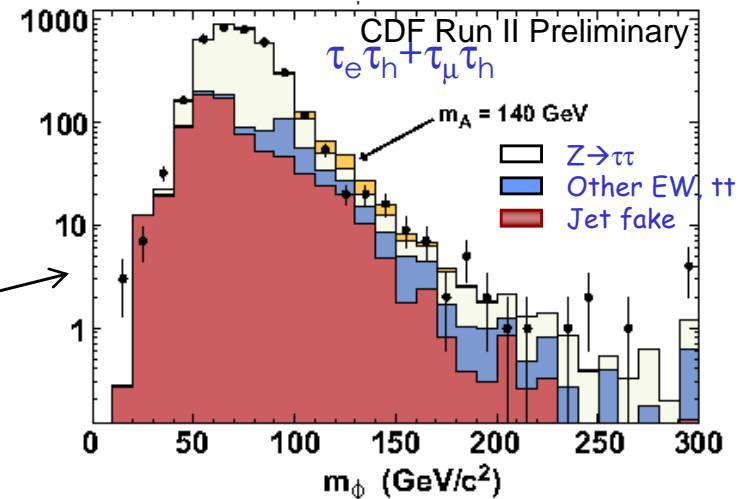
# Non-Standard Model Higgs (D0)

- Fermiophobic Higgs
  - Decay to  $\gamma\gamma$
  - Look for diphoton mass resonance
  - Limit in  $m_h$ - $\text{Br}(h \rightarrow \gamma\gamma)$  plane:
- Doubly-charged Higgs
  - Pair produced,  $4\mu$  final state.
  - Limits assume 100% BR to muons.



# Non-Standard Model Higgs (CDF)

- MSSM Higgs production cross-section enhanced at large  $\tan \beta$ .
  - **Decays to  $\tau\tau$  (10%)**
  - Decays to  $b\bar{b}$  (90%)
- Tau triggering, identification, reconstruction.
- No excess observed; limits in  $m_A$ - $\tan \beta$  plane.



1.8 fb<sup>-1</sup>

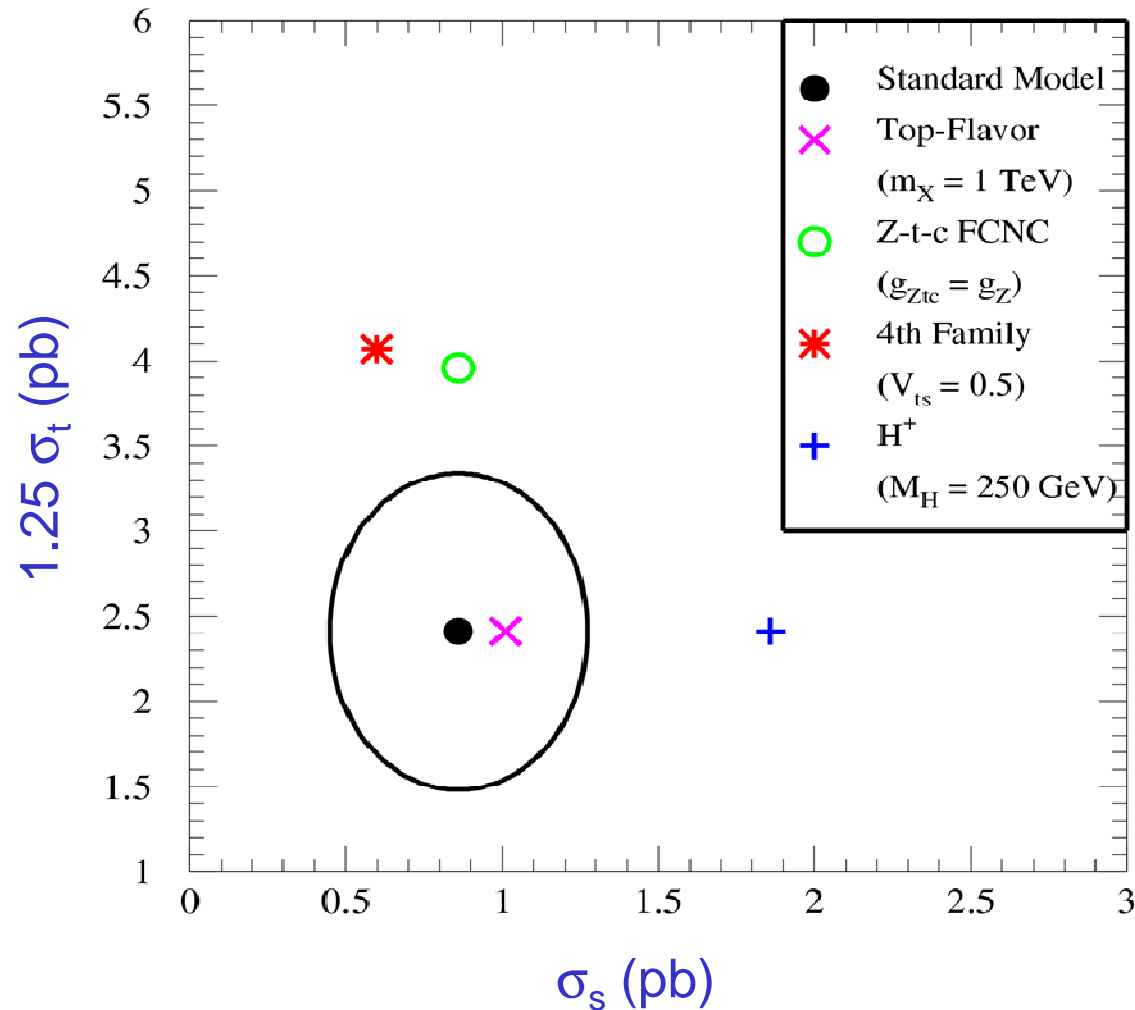
# Conclusions

- Tevatron data so far consistent with the Standard Model
  - Low-rate SM processes (single top, diboson) showing up as expected.
  - No indications of BSM physics.
- Some interesting features to keep an eye on.
- Much more data yet to come.



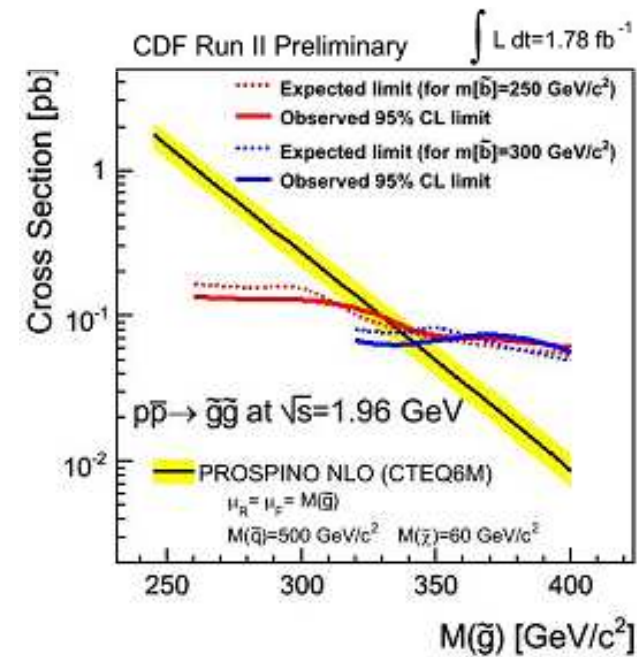
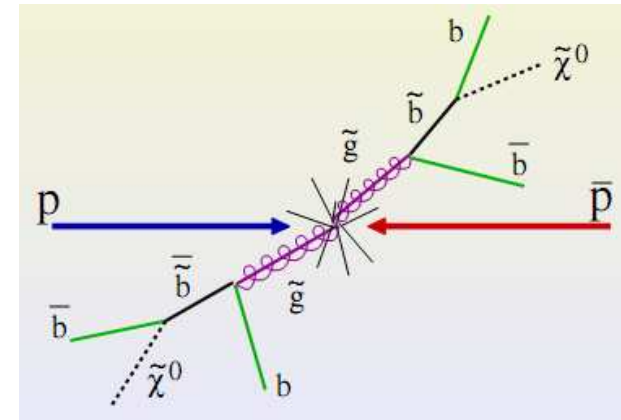
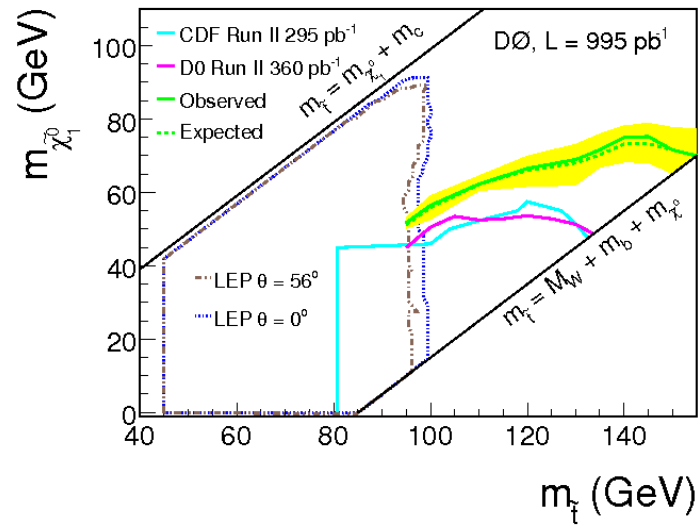
# Additional Material

# New physics from s vs t cross-section



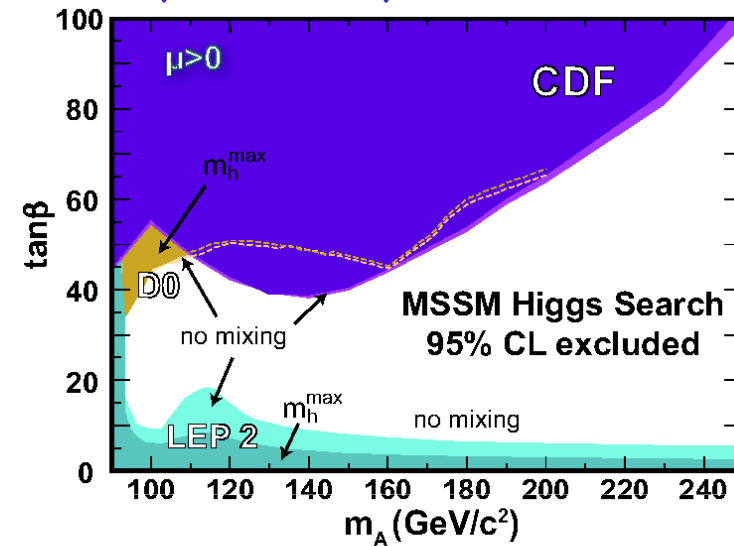
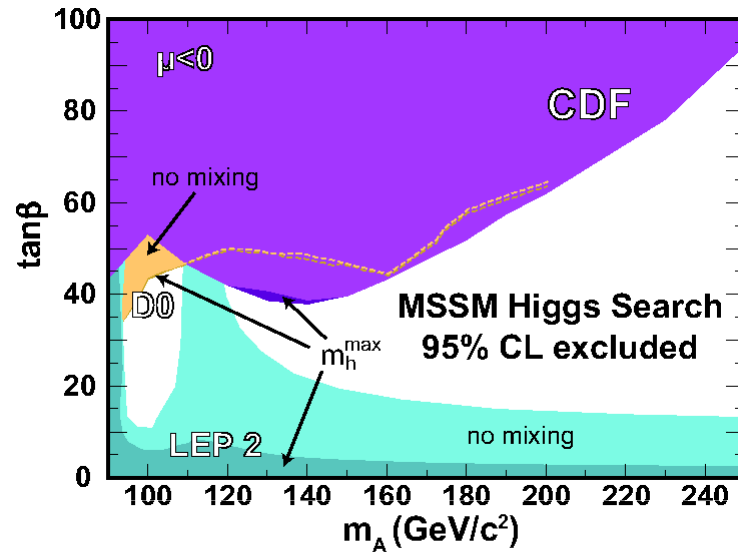
# stop/sbottom

D0 limit for  $\text{stop} \rightarrow c\chi^0$  in  $1 \text{ fb}^{-1}$

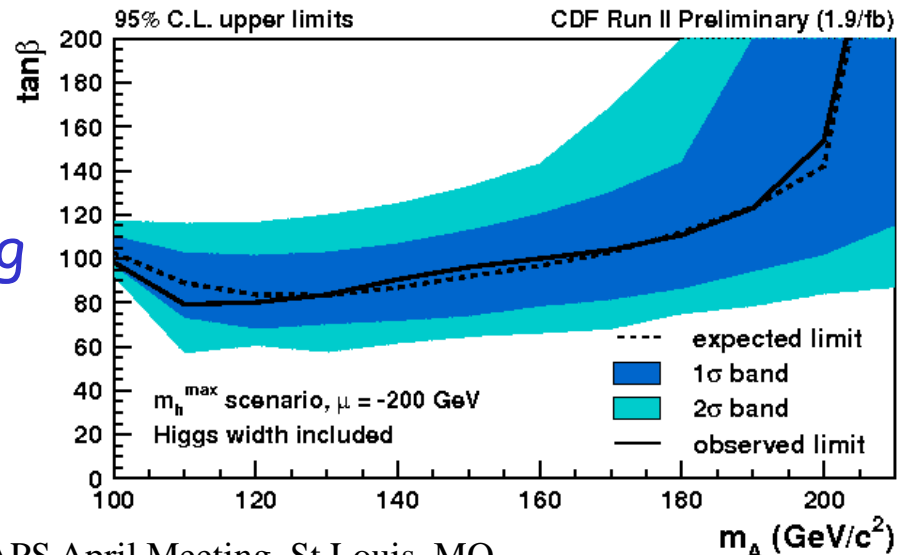


# MSSM Higgs

CDF and D0 limits together,  $\mu < 0$  and  $\mu > 0$



CDF limit using  
 $H/Ab \rightarrow 3b$



# $B_s \rightarrow \mu\mu$ constraining mSUGRA

